Project Title:	DEVELOPMENT OF AN EARTH PRESSURE MODEL FOR DESIGN OF RETAINING STRUCTURES IN PIEDMONT SOILS
Purpose:	To derive a realistic model for lateral earth pressures in piedmont residual soils, calibrated to common field insitu soil tests, for use in the design of earth retaining structures.
Subcommittee:	Structures
Organization:	University of North Carolina at Charlotte Civil Engineering Department

PI: ________________________________

J. Brian Anderson, Ph.D., Assistant Professor
The University of North Carolina at Charlotte
Civil Engineering Department
9201 University City Blvd.
Charlotte, NC 28223
Tel: (704) 687-6039
Fax: (704) 687-6953
Email: jbanders@uncc.edu

CoPI: ____

Vincent Ogunro, Ph.D., Assistant Professor
The University of North Carolina at Charlotte
Civil Engineering Department
9201 University City Blvd.
Charlotte, NC 28223
Tel: (704) 687-3101
Fax: (704) 687-6953
Email: vogunro@uncc.edu

Administrator: ________________________________

Toby A. Rufty, Contracts and Grants Administrator
The University of North Carolina at Charlotte
William States Lee College of Engineering
9201 University City Blvd.
Charlotte, NC 28223
Tel: (704) 687-2070
Fax: (704) 687-3855
Email: tarufty@uncc.edu

Submittal Date: ***April 12, 2004***

EXECUTIVE SUMMARY

The lateral earth pressure on retaining structures due to Piedmont residual soils is difficult to quantify by traditional methods and is often over predicted. Thus, large safety factors are used in retaining structure design that increase conservatism but not necessarily the engineer's confidence in the design. Much of this conservatism can be attributed to the divergence between the behavior of Piedmont residual soils and traditional cohesive and cohesionless soils.

The objective of this proposed project is to develop a simplified model for lateral earth pressure in Piedmont residual soil based on insitu soil tests. This model will be determined by measuring the lateral earth pressure behind sheet pile retaining walls in three of the geologic zones of North Carolina: the Carolina Slate Belt, the Charlotte Belt, and the Inner Piedmont.

A novel approach using instrumented sheet piles as "moment-cells" will be adapted from the analysis of piles under lateral loading. Sheets will be instrumented to measure bending moment and slope, and through differentiation, the shear stress in the wall due to earth pressure will be determined. To include the effect of joint orientation within the residual soils, an approach is proposed to bracket the two extreme conditions (joints dipping in and joints dipping out of the excavation) at each test wall site.

Based on the results of the research program, a simple lateral earth pressure model will be developed that will be a function of easily measured insitu soil properties and the joint fabric characteristics of the residuum.

TABLE OF CONTENTS

RESEARCH PLAN

Introduction

Both temporary and permanent retaining structures are used to either restrain earth movement during construction or to maintain stable elevation difference. In roadway design, these structures take the form of sheet-pile walls, mechanically stabilized earth, solider pile, and traditional gravity wall systems. The pressures on earth retaining structures result from the soil around them and any external surcharge loads. Field and/or laboratory derived soil parameters are used in classical theories, such as Rankine or Coulomb, to develop a lateral stress distribution for design.

For temporary and permanent retaining structures, designers typically use conservative estimates of the lateral load coupled with conservative limit-state design methods. This is especially true in the often inadequately characterized and highly variable soils of Piedmont region of North Carolina. Classical earth pressure distribution, based on well defined soil types, cannot adequately predict the state of stresses within these soils.

Problem Definition

Traditional methods for calculation of lateral earth pressures in residual soils over predict the actual insitu stresses. Much of this conservatism is attributable to the additional strength exhibited by Piedmont residual soils due to the fabric-type nature of the material that is overlooked in traditional soil models (i.e. Mohr-Coulomb limiting equilibrium). Unfortunately, it is difficult if not impossible to gather undisturbed samples of Piedmont residuum for laboratory testing; thus, engineers rely on insitu tests to gather strength parameters used in retaining structure design. Since these tests are calibrated to laboratory tests on **either** cohesionless **or** cohesive soils, they do not provide a true measurement of the strength of Piedmont soil. Thus, engineers often design these structures based on conservative parameters and apply conservative factors of safety. Yet, there is no direct increase in the engineer's confidence in the design.

Literature Review

Classically, the loads that control the design of these retaining structures are determined based on Coulomb, Rankine, or logarithmic-spiral theory. Although, these theories have resulted in successful earth retaining structure design, it must be emphasized that depending on the soil fabric and layered system, the results determined from these methods can be quite different from measured earth pressure acting on the structure. Researchers such as Peck (1969) and Clough and O'Rourke (1990) have investigated retaining wall pressure and earth movements due to excavations. Other case studies of worldwide experience are also presented by Long (2001).

In geotechnical engineering, the study of residual soils is a rather young topic. Most of the cases in current literature focus on the determination of material properties based primarily on work performed in the mid-atlantic and the south end of the Piedmont province. The existing literature includes works by Lutenegger et al. (2003) Waisnor et al. (2001), Mayne et al. (2000), Mayne et al. (1999), and Petersen et al. (1999). Specific to residual soils of the extreme eastern Piedmont of North Carolina, Wang and Borden (1996) and Heartz (1986) present studies of deformation characteristics and engineering properties, respectively. However, there have been no studies concerning a lateral earth pressure model for Piedmont soils, or any earth pressure data published.

Research Objective

The objective of this proposed project is to develop a simple lateral earth pressure model for residual soils based on soil fabric data and insitu soil tests. This will be accomplished by measuring the lateral earth pressure behind three to four instrumented retaining walls in Piedmont residual soils from three geologic provinces in North Carolina: the Carolina Slate Belt, the Charlotte Belt, and the Inner Piedmont. From the results of insitu soil tests and instrumented wall tests, a simple lateral earth pressure model will be developed that will be a function of measured insitu soil properties and the joint fabric characteristics of the residuum.

The proposed project will be performed in close collaboration with engineers and NCDOT personnel at both the regional and state level and will rely on heavily technical, equipment, and construction support from NCDOT units.

Research Approach/Strategy

The strategy for successful completion of the project was conceived through discussion with Mr. Njoroge Wainaina (State Geotechnical Engineer), Mr. Mohammed Mulla (Assistant State Geotechnical Engineer), and Mr. Scott Hidden (Support Services Supervisor). Direct measurement of lateral earth pressures by earth pressure cells was ruled out due to construction complications and survivability concerns. A novel approach using instrumented sheet piles as “moment-cells” was adapted from the analysis of piles under lateral loading.

Sheets will be instrumented to measure bending moment and slope, and, through differentiation, the shear stress in the wall due to earth pressure will be determined. It will be important to include the effect of joint orientation within the residual soils when planning for these test walls. Thus, an approach is suggested to insure two “bracketed” conditions occur at the test site. Two walls will be installed parallel at each site, approximately 20 feet apart. The walls will be oriented such that the general trend of the joint planes runs in the same plane. Since the joint sets will dip at some angle from the horizontal, one wall will have joints that dip into the excavation and the other will have joints that dip out of the excavation. When the soil is excavated between the walls, both walls will bend as the active earth pressure wedge develops behind the wall. Thus, only one excavation is required for two wall tests. Figure 1 shows a schematic diagram of the joint planes with respect to the proposed walls and the excavation.

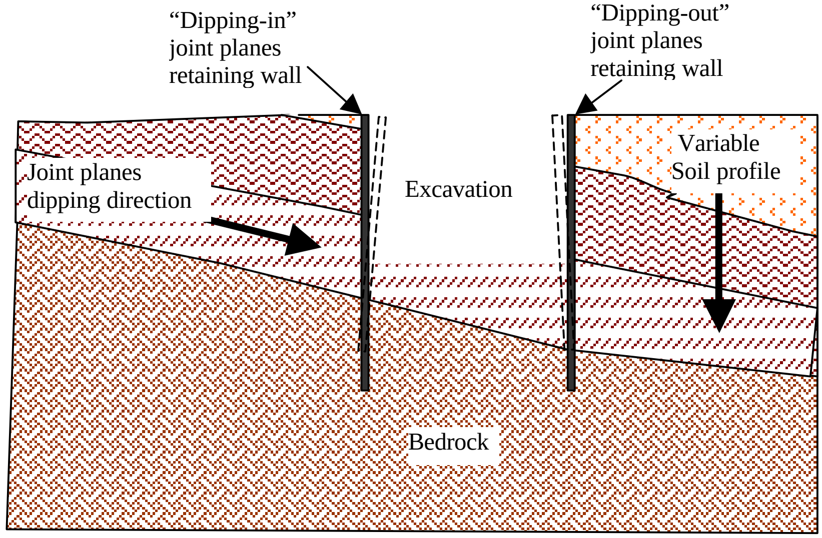

Figure1: Conceptualization of the joint planes dipping with respect to the field test walls

The bending sheets will be outfitted with a system of 5 levels of strain transducers. Welded or glued strain gages were considered too risky, thus strain transducers, manufactured by Pile Dynamics, will be used. These transducers will be placed at intervals of two feet from the base of the excavation to the ground surface. A special protective steel channel will be used to cover the transducers and protect them from driving damage. Slope will be measured using a conventional slope inclinometer. However, instead of the typical PVC, a steel box section welded to the back of the sheet pile will serve as the casing.

Research Methodology and Itemized Tasks

1. *Overview Retaining Structures*
   A detailed and extensive review of widely accepted works and literature associated with retaining structures will be completed.
2. *Collection of Existing Data*
   The historic records of earth retaining structures implemented in Piedmont residual soils and their performance will be collected and analyzed. The performance of these structures will be examined and correlated with the corresponding soil parameters.
3. *Site Selection*
   Working in close partnership with engineers and personnel of the NCDOT Geotechnical Engineering Unit, three suitable test sites located in the Carolina Slate Belt, the Charlotte Belt and the Inner Piedmont will be selected. The selection of these sites will be based on the thickness of residual soils, bedding and joint structure.

4. *Insitu and Laboratory Soil Testing*
   After the wall sites are selected, a rigorous site investigation program will be completed. NCDOT and UNCC personnel will work to perform standard penetration tests, Iowa Borehole Shear Tests, additional specialized insitu soil tests to determine the engineering properties and geologic fabric of the residuum. In addition, the probable penetration depth of the sheet piles will be evaluated.
   Where possible, undisturbed samples of residual materials will be collected for determination of engineering properties.
5. *Preliminary Numerical Simulations*
   Finite element method models will be developed to predict the earth pressure behind and deflection of the sheet pile walls based on insitu test parameters and geologic information at each site. These models will help fine tune the instrumentation and measurements for each test wall to best match the field conditions.
6. *Prototype Wall Testing*
   In order to verify the function of field instrumentation, two prototype sheet piles, one strain instrumented and one with the slope inclinometer casing, will be tested in the laboratory. The sheets will be installed with a fixed base and a point load will be applied at the opposite end to induce a moment. The strain gages will be checked and monitored during the loading process. The function of the slope inclinometer will also be verified. A third uninstrumented sheet will be tested in series with the prototype sheets to compare the bending stiffness of the instrumented and non instrumented sheet pile sections and the effects of other environmental factors on the measurement system.
   After laboratory testing, all three sheets will be driven into residual soil in the Charlotte Belt (close to UNCC) using the same procedure as the full-scale field tests to assess drivability of the sheets and the effects pile driving on the instrumentation.
7. *Full-Scale Instrumented Field Test Walls*
   The primary task of the research project will be the construction and excavation of the test retaining walls. At each of the selected sites from task 3, a pair of parallel instrumented retaining walls will be constructed, approximately 20 feet apart. Each wall will be 20 to 30 feet in length and will be constructed of sheets driven 20 feet into the ground or refusal. The soil between the two walls will be excavated 10 feet from the original ground surface. Each wall will contain three strain instrumented sheets and two slope instrumented sheets. Prior to and after excavation, slope inclinometer readings will be taken. The strain gages continually will be monitored over the duration of the excavation.
   After completing the excavation, the sheets will be removed and transported to the next site.
8. *Project Meeting*
   Soon after completion of the first wall test, a meeting is proposed to discuss the initial research findings. This will serve as a forum to examine results and adjust the scope and execution of the remaining wall tests.

9. *Analysis of Results*
   Based on the results from task 6 and the research strategy discussed above, lateral earth pressure distribution for each field sheet pile test will be determined. The results obtained for each test site will be compared and correlated to characteristics of the residual soil (thickness, bedding and joint structure). A simple displacement and earth pressure relationship based on the joint structure orientation will be proposed.
10. *Model Validation*
    The models developed in task 7 above will be correlated to the engineering properties of the residuum obtained from both laboratory and insitu tests. A relationship among earth pressure and measurable insitu soil properties will be developed and recommended. Results of the models will also be compared with classical earth pressure theory.
11. *Reporting and Publication*
    The data from each phase of the study, the results of analysis, and the project findings will be documented in a comprehensive report to the NCDOT. In addition, findings will be presented as publications and presentation to the TRB, STGEC, and Geo^3 T^2.

IMPLEMENTATION AND TECHNOLOGY TRANSFER

The main product of this proposed research project will be a model to earth pressures for design of temporary and permanent retaining structures in the Piedmont residual soils of NC. The final report will document the methodology used for this research, the laboratory and field test data, results of sheet pile wall instrumentation, findings from data analysis and conclusions and recommendations for implementing the findings. Working closely with the NCDOT Geotechnical Engineering Unit, a simple and easy to implement guideline will be developed for relating field site characterization data to earth pressure distribution in the Piedmont residual soils of NC.

BENEFIT TO NCDOT

One of the obvious and immediate benefits of the findings and the deliverables of this research project to the North Carolina Department of Transportation will be a better estimate of stress distribution for both temporary and permanent retaining wall design and analysis in typical Piedmont residual soils in North Carolina. The adoption of a more correct field verified lateral stress model could result in significant savings in future retaining structure design. Moreover, retaining structures in Piedmont soils will be designed with greater confidence and constructed with quantifiable level of safety. The simplified field test procedure will enable NCDOT personnel and other shareholders to quickly determine lateral earth pressures for retaining structure design and analysis based on Piedmont soil parameters. Since Piedmont soils cover a large area in several states in the southeast, the findings of this research project will be a highly valuable resource for retaining structures in Piedmont soils to the respective DOTs and other cooperating agencies.

NCDOT RESOURCES

As discussed with geotechnical unit personnel, the success of this project hinges on the participation of many NCDOT groups. Resources requested include:

1. Access to NCDOT historical records of retaining walls
2. Access to NCDOT sites where residual soils are identified in sufficient thickness and selected joint orientation
3. Drilling and sampling of test sites including standard penetration tests
4. Material and construction support for the sheet pile retaining walls and testing

UNCC EQUIPMENT AND FACILITIES

1. Instrumented conventional triaxial and true triaxial equipment.
2. Large direct shear box for testing large samples and geosynthetics
3. 15 Bridge Diagnostics^{TM} Strain Transducers and data acquisition unit
4. Structural lab strong floor and wall test facility with hydraulic jacks and data acquisition.
5. Mosaic computer system with finite element modeling capabilities

TIME REQUIREMENTS AND PROJECT ORGANIZATION

The estimated duration for completion of the project is 24 months. For a start date of July 1, 2004, the expected end date of the project will be June 30, 2006. Table 1 presents a brief outline of the project schedule is presented in a milestone chart.

Table 1: The milestone chart for the project.

TASK	**Months**											
	2	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**
Overview retaining structures	x											
Collection of existing data	x											
Site Selection	x	x	x									
Sampling & laboratory testing			x	x	x							
Preliminary numerical simulations				x	x							
Prototype wall testing				x	x	x						
Full-scale instrumented field test walls					x	x	x	x	x			
Proposed project meeting						x						
Analysis of results							x	x	x	x		
Model validation								x	x	x		
Reporting and publication										x	x	x

Dr. Brian Anderson will be the Principal Investigator with Dr. Vincent Ogunro as the Co-Investigator of this project. Since this project is labor-intensive, two graduate students and one undergraduate student will assist with field testing, instrumentation, numerical modeling and laboratory testing.

RESEARCHERS' QUALIFICATIONS

The PI has extensive experience in insitu testing of soils including cone penetration testing, dilatometer testing, pressuremeter testing, and standard penetration testing. He has performed tests throughout the southeast, Minnesota, and Puerto Rico. In addition, Dr. Anderson has experience in analysis and instrumentation of deep foundations. The CoPI also has broad experience in retaining structure design and instrumentation, including instrumentation of Mechanically Stabilized Earth walls. His experience in insitu soil testing includes inclinometer and field direct shear testing.

CURRENT RESEARCH PROJECTS

The PI has no current research commitments. He has pending research proposals with the Florida Department of Transportation and the Department of Defense. The Co-PI has two ongoing research projects: Capillary Barrier Performance (8 months project, ending in February 2004), funded by the Idaho National Environmental Engineering Laboratory; and Long-term Performance Assessment of Waste Management Infrastructure (36 month project, ending in August 2006), funded by the National Science Foundation.

LIST OF RELATED PUBLICATIONS

Clough, G.W., and O'Rourke, T.D. (1990). "Construction Induced Movements of Insitu Walls." *Design and Performance of Earth Retaining Structures, Geotechnical Special Publication No. 25*, ASCE, New York, NY, pp. 439-470.

Heartz, W. T. (1986). "Properties of a Piedmont Residual Soil," PhD Dissertation, Dept. of Civil Engineering, North Carolina State University, Raleigh, NC.

Long, M. (2001). "Database for Retaining Wall and Ground Movements due to Deep Excavations." *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 127, No. 3, ASCE, March, pp. 203-224.

Lutenegger, A.J., Cerato, A.B., and Harrington, N. (2003). "Some Physical and Chemical Properties of Some Piedmont Residual Soils." *Proceedings of 12th Panamerican Conference on Soil Mechanics and Geotechnical Engineering*, Patricia J. Culligan, Herbert H. Einstein and Andrew J. Whittle Eds., Cambridge, MA, June. pp. 775-782.

Mayne, P.W., Brown, D., Vinson, J., Schneider, J.A., and Finke, K.A. (2000). "Site Characterization of Piedmont Residual Soils at the NGES, Opelika, Alabama." *National Geotechnical Experimentation Sites (NGES) Geotechnical Special Publication # 93.*, Jean Benoit & Alan Lutenegger Eds., ASCE, Reston, VA, April, pp. 160-185.

Mayne, P.W., Martin, G.K., and Schneider, J.A. (1999). "Flat Dilatometer Modulus Applied to Drilled Shaft Foundations in Piedmont Residuum." *Behavioral Characteristics of Residual Soils Geotechnical Special Publication # 92* Bill Edelen Ed., ASCE, Charlotte, NC, October, pp. 101-112.

Peck, R.B. (1969). "Deep Excavations and Tunneling in Soft Ground." *Proceedings of the 7th International Conference of Soil Mechanics and Foundation Engineering*. Mexico City, pp. 225-290.

Petersen, M., Brand, S., Roldan, R., and Sommerfeld, G. (1999). "Residual Soil Characterization for a Power Plant." *Behavioral Characteristics of Residual Soils Geotechnical Special Publication # 92* Bill Edelen Ed., ASCE, Charlotte, NC, October pp. 26-42.

Waisnor, B. M., Ducote-Price, A., Jarosz, B., Duncan, J.M., and Smith, C.J. (2001). "Geotechnical Engineering within the Piedmont Physiographic Province." Report of a study performed by the Virginia Tech Center for Geotechnical Practice and Research. August.

Wang, C. E. and Borden, R. H., (1996). "Deformation Characteristics of Piedmont Residual Soils." Journal of Geotechnical Engineering, Vol. 122, No. 10, ASCE, October, pp. 822-830.